Dual-band Optical Bench for Terahertz Radiometer for Outer Planet Atmospheres (TROPA)

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Invited Paper

***Abstract*—We have developed a wide-band dual frequency spectrometer for use in deep space planetary atmospheric spectroscopy. The instrument uses a dual-band architecture, both to be able to observe spectral lines from a wide range of atmospheric species, and to allow a higher precision retrieval of temperature/pressure/partial pressure and wind profiles. This dual-band approach requires a new design for the optical bench to couple both frequencies into their respective receivers.**

I. Introduction

We are currently developing a new, wide-band dual-frequency terahertz spectrometer for planetary science, specifically targeted at the Jupiter system. Its unique characteristics are its wider tunability than previous non-astronomical submillimeter instruments (530-600 GHz, 1100-1300 GHz). Herschel HIFI, a previous instrument with similar bandwidths was part of a large space observatory massing 3300 kg with a 3.5 m diameter telescope and a total power consumption of around 1 kW [1]. Our terahertz spectrometer is targeted at 10 kg, 20 W.

At the other end of the spectrum, an earlier dual band instrument, the Microwave Instrument on Rosetta (MIRO) [MIRO], carried aboard ESA's Rosetta craft, currently on its way to comet Comet 67 P/Churyumov- Gerasimenko, operates at 190 and 560 GHz with a maximum tunability of about 10 GHz.

II. Background

The primary use of terahertz range radiation for atmospheric science takes advantage of the molecular resonances in this frequency range for spectroscopy. Spectral observation allows identification of these molecular species, and determination of their relative abundance (partial pressure) in the atmosphere. Line broadening by the effects of temperature and pressure, allows them to be profiled with altitude from the observed line shapes [2] (m*icrowave sounding*). Observing lines of a single species at two widely spaced frequencies enables correction of receiver uncertainties. Measurement of the Doppler frequency shift gives the radial velocity of the gas relative to the instrument. From this data atmospheric winds and circulation can be modeled.

For example, at Jupiter, observation of HCN, H_2O, and CH_4 will determine temperatures, pressures and wind speeds in Jupiter's stratosphere, and measurement of a large number of other species (CO, HCN, CS, CH, H_2CO, CH_3C_2H, CH_3OH plus surveys for unknowns) will determine their abundance and circulation in the atmosphere, shedding light on the physics of energy transfer between layers of Jupiter's atmosphere.

At Jupiter's moons, Ganymede, Callisto, and Io, surface properties (including age estimates) will be determined from observation of the material sputtered off the surface into space by solar ions. In the case of Io, material emitted volcanically, including SO_2, SO and NaCl, will be analyzed to explore its surface history and dynamics.

III. Principles of Operation

A. Microwave Sounding

The remote sensing of an atmosphere by its emission and absorption of electromagnetic radiation, which can be analyzed based on the radiative transfer equation. In the microwave region, the equation that describes the received radiance for an observer at a distance s=0 and a background at s=s_0,

$$T_{b,\nu} = T_{b0,\nu}\, e^{-\tau(s_0)} + \int_0^{s_0} \frac{\lambda^2}{2k} B_\nu(T) e^{-\tau(s)} \alpha_\nu(T,P)\, ds. \quad (1)$$

Here the received signal is described by a "brightness temperature" $T_{b,\nu}$, which is the received spectral intensity (W/Hz/Sr) multiplied by $\lambda^2/2k$. B_ν is the Planck function,

$$B_\nu = \frac{2kT}{\lambda^2} \frac{h\nu/kT}{e^{h\nu/kT}-1}, \quad (2)$$

where k, h, λ, ν, and T have their usual meanings. The first term in equation (1) is due to absorption of the background radiation by the atmosphere, and the second is the combination of emission and absorption of its own radiation. The absorption coefficient is $\alpha_\nu(T,P)$, a function of temperature and pressure (both functions of position s along the line of sight), and $\tau(s)$ is the total extinction, i.e. α_ν integrated from the observer at 0 to s.

B. TROPA Design

The Terahertz Radiometer instrument includes two channels, each with heterodyne front-end comprising a Schottky mixer[3] pumped by a widely tunable LO generated by a synthesizer and multiplier chain, which converts a band of frequencies down to an intermediate frequency range (IF) of 0-750 MHz. The IF is analyzed in detail by the digital spectrum

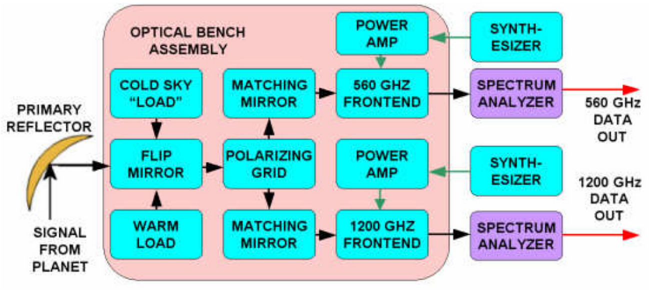

Figure 1. Terahertz spectrometer block diagram.

analyzer (back-end), all indicated in the block diagram of Figure 1.

C. *Optical Bench*

In order to receive both frequency bands via a single telescope in the 30 cm diameter range requires that the beam from the telescope be split into two signal beams leading to the two receivers. Two ways to accomplish this splitting are possible: one is a frequency diplexer sending the 560 GHz frequency band to the 560 GHz receiver and 1200 GHz band to the 1200 GHz receiver. Alternatively a polarizing power splitter can be used. The power splitter method has simplicity and lower insertion loss of its broadband architecture, but at the cost of dissipating half the signal power. However, since the receivers reject one polarization anyway, a polarizing beam splitter allows the power to be split with no additional loss over what would be achieved using the frequency diplexer. Several beam splitter configurations were considered:

1. A single compact block with the beam splitting occurring inside the block. This would be the most compact arrangement, since bulky quasi-optics are not used, and the beam from the telescope is focused directly into a wideband horn in the block.

2. A variation of the MIRO optical design [4] reconfigured in such a way that the receivers are adjacent to each other and their low-frequency pump inputs and IF outputs are on the same side of the optical bench. See Fig. 2 (a). The system incorporates four mirrors in addition to the primary and secondary reflectors: one to align the beam parallel to the mounting plate of the optical bench (called a "turning mirror", M3). Further, each receiver has its own "matching mirror" (M5 and M6) that tailors the beam from the telescope to properly match to the horn of the receiver. This allows proper illumination of the main antenna reflector at each of the two widely spaced frequency bands, necessary to gain maximum spatial resolution for each frequency. M4 re-focuses the beam and provides a more compact folded optical path.

3. A "simplified" optical design (Fig. 2b) whereby the two receiver horns are angled toward the beam splitter and cross and receive the signals directly from it without matching mirrors. This still requires at least the turning mirror (M3), and the re-focusing mirror, M4. This configuration has the advantage of compactness, and a reduced number of mirrors. The disadvantage is that the receiver horns would have to match the beams over the wide bandwidth of the receivers, which greatly complicates the horn design.

Option 1, the polarizer-in-block approach, was rejected, as it would be more lossy to have an in-block orthomode junction to split the polarizations between two receivers. Option 3, the "simplified" design was at least deferred until the next iteration, because the design of the horns is more complex. It may be considered again later in the program. For now, we are constructing the optical bench using option 2, Fig. 2a.

More details on the design current state of TROPA

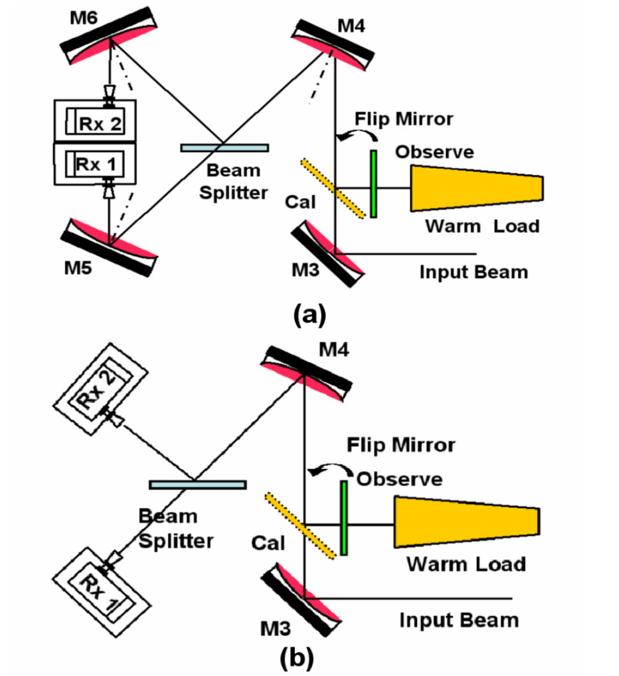

Figure 2. (a) First design with simple horns and matching mirrors. (b) Simpler optical path with matching horns replacing matching mirrors.

construction will be given in the conference presentation.

ACKNOWLEDGEMENT

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